

Comprehensive Analysis of Bioactive Compounds and Pharmacological Implications of Tulsi

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ABSTRACT

Plants are excellent sources of active components that act as natural antimicrobial agents and have been used to treat various diseases since ancient times. Tulsi is the most sacred plant of India. The *Ocimum sanctum* has many beneficial properties, antioxidative, antimicrobial, antistress, antidiabetic, antiviral, and many others. Tulsi is one of the most aromatic herbs, which is widely used in the Pharmaceutical Industry. *O. sanctum* is mostly used in the form of extract and oil.

The main secondary metabolites of Tulsi extract are Eugenol, Linalool, β -Caryophyllene, Carvacrol, Apigenin, Rosmarinic Acid, and Urosolic Acid. These are derivatives of alkaloids, phenols, glycosides, flavonoids, tannins, saponins, terpenoids, steroids, and quinones isolated from *Ocimum sanctum* and other medicinal plants. Tulsi leaf extract also inhibits the growth of pathogens, responsible for the spoilage of fresh products. Tulsi extract shows inhibitory effects against pathogens such as *Staphylococcus aureus*, *Pseudomonas aeruginosa*, *E. coli*, *Klebsiella pneumonia*, *Proteus mirabilis*, *Salmonella typhimurium*, *Salmonella phae*, *Shigella dysenteriae*, *Bacillus pumilus*, *Aspergillus spp.*, *Candida albicans*, and *Penicillium spp.* Essential oil and extract of Tulsi leaves has antiviral properties and are used extensively in medical practices. It is an excellent antimicrobial agent, so it is used in food products as an ingredient in medicine.

Keywords: Bioactive Compounds; Phytochemicals; Medicinal Values; Broad-Spectrum; Antimicrobial; Healthy Liquid; Antidiabetic; *Ocimum sanctum*; Therapeutic Potential; Adaptogenic.

1. Introduction

Ayurveda is the approach to most of the modern health problems as it includes promoting good health improving overall body function systems and preventing diseases through healthy practices which comprises of ingestion of fresh and minimal processed foods, the use of formulas that tackles aging and diseases, proper detoxification techniques and regular consumption of medicinal herbs that will enhance the body's capability to maintain the balance while facing different stressors.

In Ayurvedic medicine, Tulsi is esteemed as an “**elixir of life**” due to its extensive therapeutic properties, including adaptogenic, antimicrobial, anti-inflammatory, and antioxidant effects [1]. Tulsi is an aromatic shrub in the family of herbs (lamiaceae), which is native to the Indian subcontinent and widespread as a cultivated plant throughout the Southeast Asian tropics. Tulsi is known basically for its medicinal purposes. Tulsi can be used in powder or aqueous form and in making herbal tea or mixed with other herbs or honey to enhance its medicinal value. From ancient times, people used the oil extracted from Tulsi to cure different types of poisoning, stomachache, common cold, headache, malaria, inflammation, and heart disease.

It has many properties, it as expectorants, analgesics, anti-emetics and antipyretic, stress reducers and inflammation relievers, and as anti-asthmatic, hypoglycaemic, hepatoprotective, hypolipidemic, and immunomodulatory agents. Its antimicrobial efficacy against a range of pathogens further underscores its role in supporting immune health [2].

Many skin diseases, like soft tissue infection (SSTIS) happen because of *Staphylococcus aureus*, *Pseudomonas aeruginosa*, and *Escherichia coli*. So, physicians prescribed Tulsi oils to cure these moderate types of skin diseases. These types of herbs are rich in a wide variety of secondary metabolites such as tannins, phenolic compounds,

alkaloids, flavonoids, etc., which enhance growth, innate immune response, and resistance against the pathogen. Tulsi also contains many anti-inflammatory properties and compounds that help in modulating both cellular and humeral immunity. Some of the tulsi species like *Ocimum basilicum*. L. contains (-) – linalool (30-40%), eugenol (8-30%), methyl chavicol (15-27%), and gamma caryophyllene as major constituents. Minor Basil oil constituents are (+) – delta-cadinene, 3-carene and alpha humelene, citral, and (-)- transcaryophyllene [3]. The Tulsi plant also contains camphor, caryophyllene oxide, cineole, methyl eugenol, limonene, myrcene, and thymol, which help as an insect repellent. Its oil can be used to abate the growth of mosquitoes. It contains natural constituents like phytoconstituents and EO, which can help treat various ailments and human health problems in this era.

1.1. Study Objectives

- 1) To assess Tulsi's pharmacological characteristics, such as its adaptogenic, antibacterial, anti-inflammatory, and antioxidant effects.
- 2) To look at Tulsi's traditional and ethnomedical use and compare them to current pharmacological research.
- 3) To examine the chemical makeup of phytochemicals and essential oils (such as terpenoids, flavonoids, and phenolics) present in various Tulsi plant sections.
- 4) To investigate the potential of chemicals obtained from tulsi as building blocks for the creation of novel nutraceuticals or medicinal agents.
- 5) To research Tulsi's immunomodulatory and stress-relieving qualities and how they may be used to treat chronic illnesses.

2. Active Chemical Composition of Tulsi

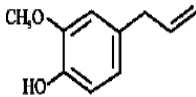
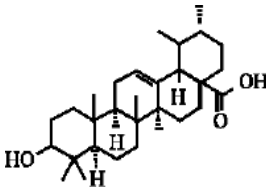
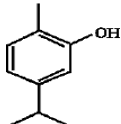
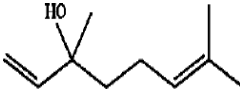
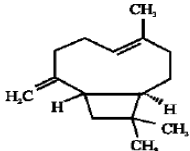
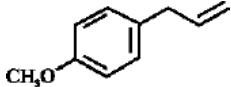
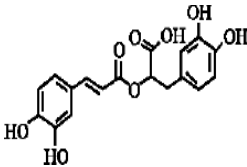
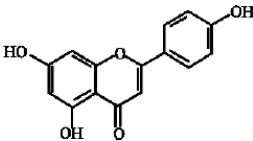
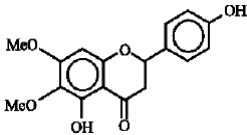
The chemical composition of tulsi is quite complex (Table 1). It is either 1-hydroxy-2-methoxy-4-allylbenzene or eugenol. This chemical composition is made up of a variety of compounds found throughout the entire plant and has antibacterial, adaptogenic, anti-inflammatory, antioxidant, and immune-modifying properties. The extract of Tulsi leaves contains a small amount of volatile oil that contains phytochemicals such as aldehyde, terpenes (sesquiterpenes, monoterpenes), and phenols, in addition to a small amount of saponins, tannins, glycosides, quinone, phlobatanin, flavonoids (orientin & vicenin), steroids, coumarin, and alkaloids [4].

The primary active components in the aqueous extract of Tulsi leaves are eugenol, urosolic acid, carvacrol, rosmarinic acid, α & β -caryophyllene, linalool, euginal (also known as eugenic acid), β -elemene, geraneol, and ocimene [5]. Other active ingredients in tulsi extract include α -thujene, isothymusin, octane, α -pinene, oleanolic acid, cirsimaritin, toluene, apigenin, nonane, β -pinene, isoborneol, camphene, α -guaiene, sabsinine, ethylbenzene, borneol, germacrene D, α -amorphene, dimethylbenzene, lactate limocene, myrecene, and p-cymene. The compounds that include so-eugenol include butylbenzene, ocimumoside A and B, γ -humulene, α -cubebene, α -terpeneol (1.7–7%), terpinolene, α -selinene, β -selinene, α -humulene, borneol, elemol, and nerolidol [6,7].

The alcoholic extract of the aerial parts (leaves, stem, and flower) of *O. sanctum* has been found to contain apigenin, methyl eugenol, urosolic acid, linalool, β -caryophyllene, stigmesterol, orientin, luteolin,

isorientin, molludistin, vitexin, triacontanol ferulate, aesculetin, chlorogenic acid, circineol, caffiec acid, isovitexin, aesculin, gallic acid, and procatechuic acid [8]. These are FDA-approved food additives that are found naturally in tulsi [9].

Table 1. Primary active constituents of *Ocimum sanctum* [10,11]

S.No.	Name of Bioactive constituents	Chemical Formula	Structure of Bioactive Constituents	Properties
1.	Eugenol (1-hydroxy-2-methoxy-4-allylbenzene)	C ₁₀ H ₁₂ O ₂		Antimicrobial, Anti-cancer agent, Antiinflammatory, Antidiabetic, Cardioprotective, Hypolipidemic & Hepatoprotective agent.
2.	Urosolic acid (2,3,4,5,6,7,8,8a,10,11,12,13,14b-tetradecahydro-1H-picene-4a-carboxylic acid)	C ₃₀ H ₄₈ O ₃		Antitumor, Antimicrobial, Anti-viral activities, Hepatoprotective, Anti-inflammatory, Anti-ulcer & Anti-hyperlipidemic.
3.	Carvacrol (5-isopropyl-2-methylphenol)	C ₁₀ H ₁₄ O		Anti-cancer agent, Antioxidant, Antibacterial, Anti-insecticidal.
4.	Linalool (3,7-dimethylocta-1,6-dien-3-ol)	C ₁₀ H ₈ O		Antibacterial, Antiviral, Antifungal, Anti-cancer agent.
5.	Caryophyllene (4,11,11-trimethyl-8-methylene-bicyclo [7.2.0] undec-4- ene)	C ₁₅ H ₂₄		Anti-cancer agent, Antioxidant, Antimalarial, Antiviral.
6.	Estragol (1-allyl-4-methoxybenzenes)	C ₁₀ H ₁₂ O		Antidiabetic, Antistress.
7.	Rosmarinic acid ((2R)-2-[[[(2E)3(3,4-Di-hydroxy-phenyl)-1-oxo-2-propenyl]oxy]-3-(3,4-di-hydroxy-phenyl) propanoic acid).	C ₁₈ H ₁₆ O ₈		Immunomodulatory, Antimicrobial, Anticancer, Anti-inflammatory
8.	Apigenin (5,7-dihydroxy-2-(4-hydroxyphenyl)-4H-1-benzopyran-4-one)	C ₁₅ H ₁₀ O ₅		Antiviral, Antibacterial, Antioxidant, Antiinflammatory.
9.	Cirsimaritin (5,4'-dihydroxy-6,7-dimethoxyflavones)	C ₁₇ H ₁₄ O ₆		Cardio protective, Anti-ulcer, Antistress.

3. Pharmacological Implications of Tulsi

3.1. Anticancer

Recent studies have continued to explore the anticancer properties of *Ocimum sanctum* (commonly known as Tulsi), particularly its effects on various cancer models. While specific recent studies on Sarcoma-180 solid tumors are limited, several investigations have demonstrated Tulsi's efficacy against different cancer types.

A study published in the *African Journal of Biomedical Research* investigated the effects of ethanolic leaf extract of *Ocimum sanctum* on DMBA-induced breast cancer in Swiss albino mice. The results showed a significant 47% reduction in tumor volume and notable improvements in liver and kidney biomarkers, indicating both anticancer and protective effects of the extract [12].

Research published in *Scientific Pharmaceutics* examined the impact of the ethanolic extract of *Ocimum sanctum* on human lung adenocarcinoma (A549) cells. The study found that the extract inhibited cell migration by downregulating integrins $\alpha\beta3$, $\alpha5\beta1$, and VEGF, suggesting potential anti-metastatic properties [13]. An earlier study demonstrated that ethanolic extract of *Ocimum sanctum* induced apoptosis in Lewis lung carcinoma cells, highlighting its potential in lung cancer therapy [14].

3.2. Antifungal activity

Aspergillus fumigates, *Aspergillus niger*, *Candida albicans*, *Cryptococcus neoformans*, *Microsporum cassis*, and *Sporotrichum schenkii* are all well combatted by tulsi. *Ocimum sanctum* extract has been tested against a number of well-known fungal organisms, including *Fusarium moniliforme*, *Aspergillus flavus* and aflatoxin B1 (AFB1) production, *A. niger*, *Aspergillus repens*, *Curvularia lunata*, and *Candida albicans*. Tulsi's antifungal qualities are currently being assessed in new research using various dosage forms and methodologies [15].

3.3. Antiviral

Tulsi leaf essential oils, such as eugenol, have antiviral properties. Hematopoietic Necrosis Virus (IHNV) [16], polio virus type 3, herpes virus (HSV), hepatitis B virus, and New Newcastle Disease Virus are among the viruses against which *Ocimum sanctum* extracts exhibit antiviral efficacy. Polio type 3 virus replication in VERO cells is inhibited by an ethanolic extract of Tulsi plant leaves at concentrations ranging from 22.5 mg/ml. Linalool, apigenin, and ursolic acid—some of the plant's isolated constituents—have broad-spectrum antiviral activity against DNA viruses, including adenoviruses and RNA viruses [17]. Its effectiveness against poultry's Newcastle disease has also been demonstrated by one study.

3.4. Antiarthritic activity

The activity of OS fixed oils was found to decrease the width of the inflamed paw in rats with formaldehyde-induced arthritis. Rats' arthritic problems significantly improved after receiving fixed oils intraperitoneally every day for ten days. By lessening the effects of carrageenan and some other inflammatory mediators (such as serotonin, bradykinin, histamine, and PGE2), the fixed oil reduces inflammation [18].

3.5. Antipyretic activity

Typhoid-paratyphoid A/B vaccine-induced pyrexia was used to assess the fixed oil's antipyretic properties. The fixed oil was found to have prostaglandin inhibitory activity, and the decrease in febrile response suggests that it has antipyretic properties [19].

3.6. Anticataract activity

A cataract experiment was conducted in which rats were given 30% galactose to create a cataract, and rabbits were given 1 g/kg of naphthalene to generate a cataract. There was a delay in the cataractogenesis process. It postponed the development of cataracts and their subsequent maturity [20].

3.7. Adaptogenic/antistress activity

In swimming mice, the aqueous extract of OS reduces stress-induced ulcers and milk-induced leucocytosis while increasing physical capacity (survival time). Among other things, adaptogen causes a reduction in the severity of stress, negativity, infection, emotional problems, and illness [21]. It is well recognized that tulsi is a good adaptogen. Physical endurance is increased by the alcoholic extract of OS.

3.8. Anticoagulant activity

The OS fixed oil (3 ml/kg) demonstrates a prolongation in blood clotting time in a response that is comparable to aspirin (100 mg/ kg). This is due to the anti-aggregator action produced by Tulsi oil on platelets [22].

3.9. Anthelmintic activity

In vitro tests using the *Caenorhabditis elegans* model shown strong anthelmintic action for both eugenol and *Ocimum sanctum* essential oils. The ED₅₀ for eugenol was 62.1 µg/ml. The main constituent of the essential oil, eugenol, is proposed as the probable anthelmintic principle. When compared to albendazole, ursolic acid, which is present in tulsi, has a significant ability to paralyze and kill worms [23].

3.10. Antidiabetic activity

According to one study, Tulsi has antidiabetic properties: in diabetic rats, the aqueous extract of Tulsi dramatically reduced blood glucose levels [24]. The hypoglycemic impact of tulsi has also been linked to a decrease in fasting blood sugar levels and HBA1c, according to other research. Additionally, tulsi works well for metabolic disorders and can be used in conjunction with other treatments. It helps with liver illness and enhances the breakdown of poisons through metabolism. It lowers fasting blood glucose and aids in balancing insulin-mediated metabolism and plasma glucose levels.

3.11. Cough and Sore Throat

Tulsi plant is a very effective component of many Ayurvedic cough syrups. The leaves treat cold and flu when chewed. Boiled water of leaves is used in case of a sore throat to impart a soothing effect. Since ancient times, tulsi has been used for minor throat infections and coryza cough as an inhalation without any adverse effects in children [25,26].

3.12. Antihyperlipidemic effect

The purpose of the fixed oils is to decrease cholesterol. Research on rats fed a high-fat diet demonstrated that *Ocimum sanctum* had a lipid-lowering effect. It restores lipids to their natural state and prevents lipid peroxidation, which is the process by which oxidation degrades lipids [27]. The primary causes of the impact were linoleic and linolenic acids.

3.13. Radioprotectant

At low and non-toxic levels, the flavonoids, such as vicenin and orientin, found in *O. sanctum* leaves, protect human lymphocytes from the clastogenic action of radiation. When administered in conjunction with WR-2721, the *sanctum* leaf extract protects bone marrow and lessens its toxicity at greater dosages [28].

3.14. Antimicrobial activity

Pseudomonas vulgaris, *P. aeruginosa*, *B. subtilis*, *B. anthracis*, *S. aureus*, and *E. coli* are all significantly inhibited by the essential oil of tulsi leaves. Leaf extracts, both alcoholic and aqueous, have the potential to be highly efficient antibacterial agents. *Shigella dysenteriae*, *P. aeruginosa*, *Salmonella typhimurium*, *E. coli*, *K. aerogens*, *P. mirabilis*, *Vibrio cholerae*, and *S. aureus* are among the enteric pathogens that the extract effectively combats [29]. The antibacterial properties of seeds were also investigated, and it was shown that *P. multocida*, *E. coli*, *B. subtilis*, and *S. aureus* were inhibited in their growth by the crude, supernatant, residual, and dialyzed samples that were extracted from the seeds.

Anthrobacter globiformis, *Bacillus megaterium*, *E. coli*, *Pseudomonas spp.*, *S. aureus*, *S. albus*, and *Vibrio cholerae* are among the bacterial strains that the essential oil effectively combats, as are pathogenic fungi such as *Alternaria solani*, *Candida guilliermondii*, *Colletotricum capsici*, *Curvularia spp.*, *Fusarium solani*, and *Helminthosporium oryzae* [30]. Both Gram-positive and Gram-negative bacteria can be inhibited by the essential oil. Tulsi seed oil has significant antibacterial qualities, although alcoholic and aqueous extracts are helpful against intestinal infections.

3.15. Healthy liquid

Consuming tulsi daily is just as beneficial to your health as yoga since it nourishes your mind, body, and soul while also promoting calm and a sense of freshness throughout your body. Like the benefits of regular exercise, tulsi has a calming impact that helps you think clearly and promotes mental calmness. The benefits of tulsi for memory and cognition are different from those of caffeine-containing drinks like tea and coffee, which can have negative effects on the body and mind. Additionally, unlike caffeine, tulsi does not cause physical dependence, hence, consistent use of tulsi is safe from negative effects.

Tulsi has been shown in numerous studies to be beneficial against stress, improve endurance and the body's ability to use oxygen efficiently, boost immunity, lower inflammation, protect against radiation, slow down aging, support the heart, liver, and lungs, and have antioxidant, antiviral, and antifungal qualities. To treat a wide range of illnesses, including the common cold, cough, headache, flu, asthma, fever, colic pain, sore throat, bronchitis, hepatic diseases, malaria fever, as an antidote for snake bite, flatulence headaches, fatigue, skin diseases, wounds, insomnia, arthritis, influenza, digestive disorders, night blindness, and diarrhea, various plant parts have been used in Ayurvedic medicine for centuries. In order to assist the body and mind cope with various physical, chemical,

emotional, and viral stressors and regain physiological and psychological functioning, tulsi acts as an adaptogen. Such significant and health-promising potential, in addition to its highly specific therapeutic actions, paved the way for the broad range of Tulsi's traditional medical uses, and also contributes to its mythological importance and religious sanctity.

4. Conclusion and Future Suggestions

As a part of previous work on antimicrobial activity of different heterocyclic compounds [31-35], here we presented a review of Bioactive Compounds and Pharmacological Implications of Tulsi. The thorough examination of Tulsi's (*Ocimum sanctum*) bioactive components and pharmacological implications highlights the plant's enormous therapeutic potential and supports its long-standing use in traditional medical systems like Ayurveda. The plant's diverse range of pharmacological actions is attributed to its abundance of phytochemicals, which include terpenoids, flavonoids, phenolic acids, and essential oils. Tulsi's effectiveness as an adaptogen, immunomodulator, antibacterial, antioxidant, and anti-inflammatory has been validated by scientific research. These characteristics lend credence to its use in the prevention and treatment of a wide range of illnesses, from infections and metabolic problems to ailments brought on by stress.

Even while our knowledge of Tulsi's therapeutic benefits has advanced significantly, there are still a number of unanswered questions that need to be answered. There are currently few human clinical trials to verify efficacy, safety, and dosage standardization; most research is preclinical. Furthermore, nothing is known about the synergistic interactions among its various bioactive components, particularly in complex medical diseases. To provide consistent therapeutic results, extract standardization and active principle identification are also essential.

In order to determine treatment efficacy and safety profiles in humans, future research should concentrate on carrying out carefully planned clinical trials. The mechanisms of action and bioavailability of the active ingredients in tulsi require further molecular and pharmacokinetic research. Its clinical efficacy may also be improved by study into the creation of Tulsi-based medications and nutraceuticals, including innovative delivery methods. Selecting the most effective varieties for particular medical uses can also be aided by investigating the pharmacological variations among different Tulsi species and cultivars.

Declarations

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Competing Interests Statement

The author declares no competing financial, professional, or personal interests.

Consent for publication

The author declares that she consented to the publication of this study.

Authors' contributions

Author's independent contribution.

Informed Consent

Not applicable.

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